A study of thermal comfort in outdoor urban spaces in respect to increasing building height in Dhaka

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ABSTRACT: **Thermal environment of urban spaces plays a great role on the quality of life in a city. It directly affects people's behaviour and usage of outdoor spaces. Therefore, an environmentally conscious urban design solution should give high priority to the thermal comfort implications of urban microclimate. Deterioration of urban microclimate due to unplanned construction of built forms which is largely the outcome of uncontrolled urbanization is a major concern in Dhaka. Regarding the context of Bangladesh where climate change is a crucial issue, a proper arrangement of urban blocks with comfortable outdoor spaces can positively contribute to mitigate the harmful impacts of urban climate. The study of urban thermal environment and outdoor comfort demands an urgent thought specially due to the introduction the new building construction rule 2008. The rule encourages a high density urban development through a relaxed building height and plot coverage rules and regulations. Building height, distance between buildings and street widths are important design features which need to be considered at the design stage of urban outdoor spaces. The impact of the rule is being reflected in the recent high-rise characters in city's residential and commercial areas. The commercial areas in particular are being hastily filled up with high-rise structures under fast urban expansion. It is becoming increasingly difficult to ignore the unfavourable impact of built forms on urban micro-climate. These high rise buildings built to achieve the highest commercial benefits with least consideration for climatic issues are a large contributor of urban heat islands. Uncomfortable urban microclimate not only affects urban life on outdoor spaces but also increases energy demand of buildings. This study attempts to examine the role of physical configuration of urban canyons in controlling the microclimate. For this study, a number of existing urban canyons in Dhaka city have been chosen which are generated by two rows of high-rise structures with varied high H/W ratio and solar orientation. It will observe the air temperature, humidity, mean radiant temperature, mutual shading, sky view factor and wind speed which represent the microclimatic characteristics of the canyons. Finally, the aim of this study is to explore the role of urban planning and urban design in creating favourable urban micro-climate so that the experts are aware of its consequences at the early design stage. Integration of climatic considerations into city planning and design can thus contribute to sustainable urban development as well as mitigation of the adverse impacts of climate change.**

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1. INTRODUCTION

Favourable microclimate has a considerable impact on city's outdoor activities as well as urban life [1, 2]. Recent evidences claim that outdoor spaces in a city which are thermally comfortable have an increasing social and economic benefit as they attract local residents, vendors, office workers, students etc and ultimately assists in monetary outcome as well as social interaction [3, 4]. In fact, thermally comfortable outdoor spaces in different parts of the city often turn into public gathering places thereby fostering a high-quality urban life. Unfortunately, due to rapid urbanization trend the outdoor urban public spaces in Dhaka are diminishing every day. Specially in the commercial areas due to high land price and scarcity of land outdoor spaces are becoming meagre and the thermal comfort in these areas are so far a matter of least concern. A study of vernacular architecture shows that outdoor spaces has always played a very important role as the indoor spaces in tropical countries like Bangladesh [5]. Many of the social, economical activities like crops processing, cooking, eating, sewing, pottery making, gossiping and even schooling takes place in the outdoor spaces in a traditional vernacular house. Regarding the context of Dhaka a comfortable microclimate is therefore a prerequisite for frequent carrying out of outdoor activities.

Due to increasing number of buildings the urban heat island effect is a common phenomenon in tropical cities like Dhaka. The impact of heat island is experienced in the elevated air temperature in high density urban areas which is considerably higher than the nearby area [6]. The temperature of an urban area can be even 11^0C higher than the surrounding country side [7]. The overheated outdoor context in cities increases the energy demand of buildings to create comfortable indoors. According to Steemers [8] the impact of the built environment on urban microclimate has to be dealt with utmost importance as buildings are the largest consumer of energy. A study of urban canyons in Greece shows that the cooling load for urban buildings becomes double when the mean heat island intensity exceeds 10^0C [6]. Therefore comfortable urban microclimate should be one of the major considerations in reducing the energy demand of buildings. Also in case of naturally ventilated buildings comfortable outdoor urban environment can play a great role in creating comfortable indoor environments [5].

The study addresses the hypothesis that it is actually possible to achieve comfortable urban microclimate through a careful urban arrangement. For this study, an urban canyon in Banani have been chosen considering its geometry and solar orientation. It can be considered that due to high mutual shading the urban canyon of high-rise buildings with narrow roads in tropical cities like Dhaka is likely to have a lower air temperature during the day hours than its neighbouring urban canyons with lower building heights and comparatively wide roads. But again absorption of solar radiation will be higher in case of high rise structures, high concentration of building masses and paved surfaces coupled with reduced vegetation. Therefore it is important to study if high mutual shading coupled with high solar absorption in high rise structures is really able to create a significant impact on outdoor thermal comfort. This study intends to devise strategies for urban planning and design to build comfortable urban microclimate by creating mutual shading in the context of tropical countries. It will evaluate the thermal comfort factors for the existing urban canyon with high-rise structures and high H/W ratio (or low W/H ratio). The thermal environment will be assessed in terms of relative humidity, wind velocity, mean radiant temperature and air temperature of the canyon at different times of the day. Then comfort response from individual passer bys through that canyon will be recorded and compared in the thermal comfort scale.

2. OBJECTIVE:

The objective of this study is to analyse the thermal impact of recent high-rise structures on urban outdoor spaces.

3. RESEARCH CONTEXT

An urban microclimate is the consequence of several parameters among which building height is an important issue to consider. The other parameters include: "the size of the city, orientation and width of streets, density of the built-up area and the presence of parks and other green areas" [9]. An unplanned high-rise environment can lead to a hostile microclimate in a city [10]. According to Nikolopoulou *et al* [3] it is possible to control the urban microclimate through a careful arrangement of urban blocks. Until the formulation of the new Building Construction rule 2008, the highest limit for building height for residential and commercial development in Dhaka city was 6 storeys and 20 storeys (for upto 70 ft front road) respectively. There was however no height limits for commercial buildings in case of 300 ft front road. With the introduction of Floor Area Ratio (FAR) in 2006 residential buildings can also be more than ten storied high depending on plot sizes. Residential plots in Dhaka are mostly around 5 Katha (3600 sft) and as per the new rule maximum height for this plot is 8 storeys ; which means residential areas already has significant number of high rise structures. For commercial buildings of 10 Katha (7200 sft) plot, height limit as per the new rule is 15 stories, whereas according to the earlier rule only 9 stories were permitted for the same situation . Under this circumstance the study of the impact of the high rise buildings on urban microclimate can assist in devising strategies for comfortable outdoor spaces in Dhaka.

4. METHODOLOGY

Thermal comfort study for outdoor spaces mainly encompasses two types of spaces: open public spaces where people gather for resting purpose and streets and routes which people use for communication [3]. This study is concerned with the later one where people are believed to prefer a particular route to avoid the uncomfortable ones. This study involves a field based research. The basic idea behind the field work is to figure out any possible deviation from the average temperature of the city with the microclimates in urban canyons and evaluate the outdoor comfort level. In a field study method a highly randomised sampling of subjects are possible which is unlikely to achieve in typical chamber studies [5] .The field work was carried out to collect comfort sensation or opinion on comfort level from number of subjects to predict the comfort level in the canyon. The subjects were randomly selected because it is considered that in an outdoor environment a person is usually not aware of his/her thermal comfort state [5]. In a predetermined thermal comfort study a person may become over alert about personal comfort judgement. To avoid this over conscious response a randomised mode of selection was chosen. Again, based on the nature of the job or occupation the respondents were grouped into two kinds; i) indoor type (job nature is predominantly indoor i.e. office worker) and ii) outdoor type (job nature is predominantly outdoor i.e. vendors) as the comfort sensation may be influenced by the state of immediate thermal environment the subject was belong to. The comfort sensations were noted during the most uncomfortable part of the day from 12:00 pm to 3:00 pm considering the fact that if the canyon performs satisfactorily during the high temperature periods, it is supposed to remain comfortable during rest of the periods. Each subject's thermal comfort judgement was recorded as per his/her age, gender, clothing, activity and temporality (degree of exposure to outdoor environment) level besides corresponding physical thermal parameters such as relative humidity, mean radiant temperature, air temperature and wind speed.

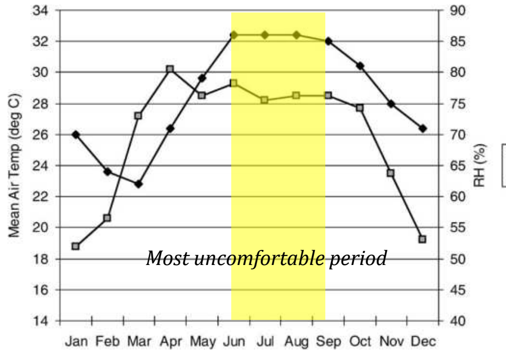

Figure .1. Mean air temperature and relative humidity of Dhaka city [5]

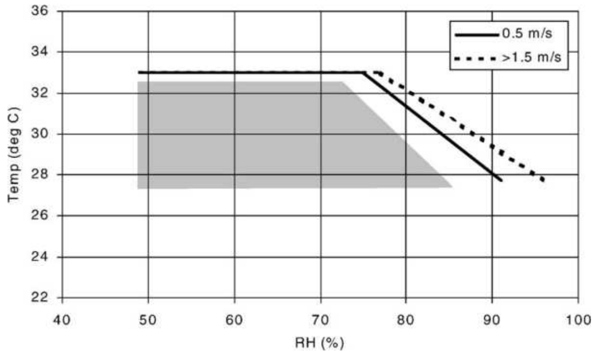

Figure 2. Outdoor comfort zone for summer in Dhaka. [5]

The field study was carried out during the hot-humid season, particularly in July and August when a high range of air temperature is coupled with high relative humidity and creates an uncomfortable environment [5]. During this period temperature ranges from 24.6^{0}C to 31.8^{0}C and relative humidity ranges between 70% and 80% (Fig 1). Hand held instruments were used to record the climatic data which included Temperature and Vane Anemometer, Humidity and Temperature Meter, Pyranometer and Light Meter. The output of questionnaire survey with comfort response from randomised subjects was plotted in Fanger's seven point thermal sensation scale [11].

5. THERMAL COMFORT AND THE CONTEXT OF DHAKA

Building designers are mostly concerned about achieving comfortable environment in the interiors. But in tropical countries like Dhaka outdoor environment is equally important. In the outdoor spaces in Dhaka we see a preference for shaded spaces and exposure to air flow [12]. Further studies [5] show that in tropical climates like Dhaka under still air conditions for people wearing typical summer clothes (.4 to .5 Clo) and being involved in sedentary activities, the comfortable temperature ranges from 28.5^0 C to 32^0 C at an average relative humidity of 70%. The range is an indication of tolerance to high temperature and humidity. Due to the socio economic context very small number of people has access to the air conditioned spaces. Therefore thermal comfort scales developed in the colder regions of the western world is not applicable for Dhaka [12]. Fig 2 shows the outdoor comfort zone for summer in Dhaka.

Dhaka is located at 23.24°N, 90.23°E which falls under tropical Monsoon climate with a distinct warm-humid rainy season, a hot-dry summer and a short cool-dry or winter season (Fig. 1). The study area is located in north-eastern part of Dhaka with a high population and building density (Fig.3). The canyon is in Banani Commercial zone and has 32 plots and 27 buildings. There are still 5 vacant plots in the site where construction of high rise structure has only started.

Figure .3. Google image of the study area

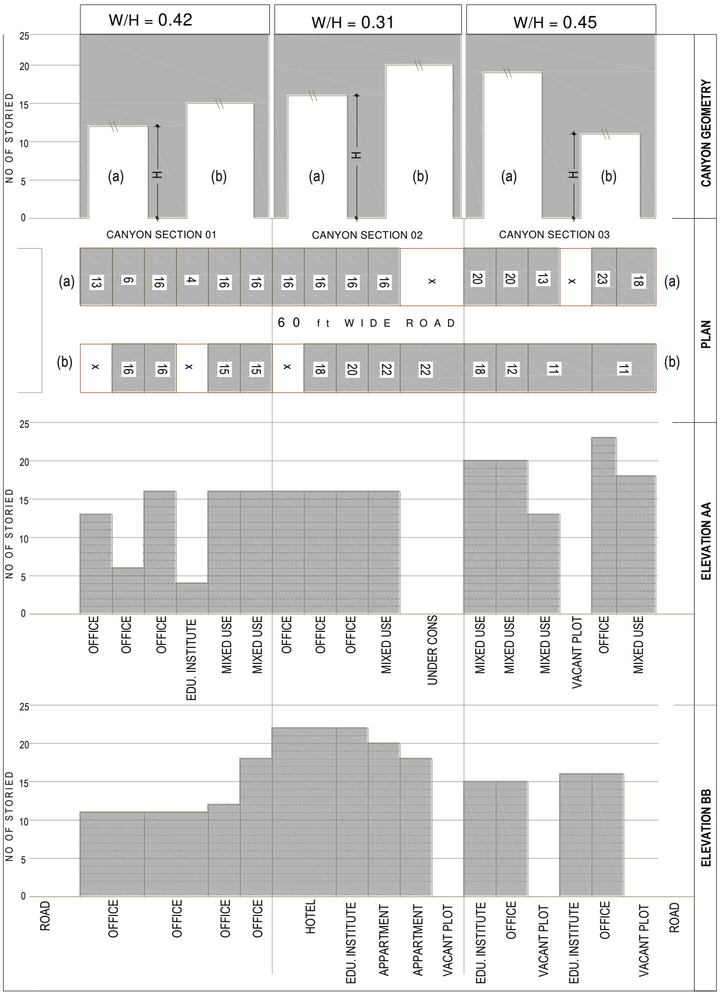

Figure.4. Geometry and landuse profile of the study canyon

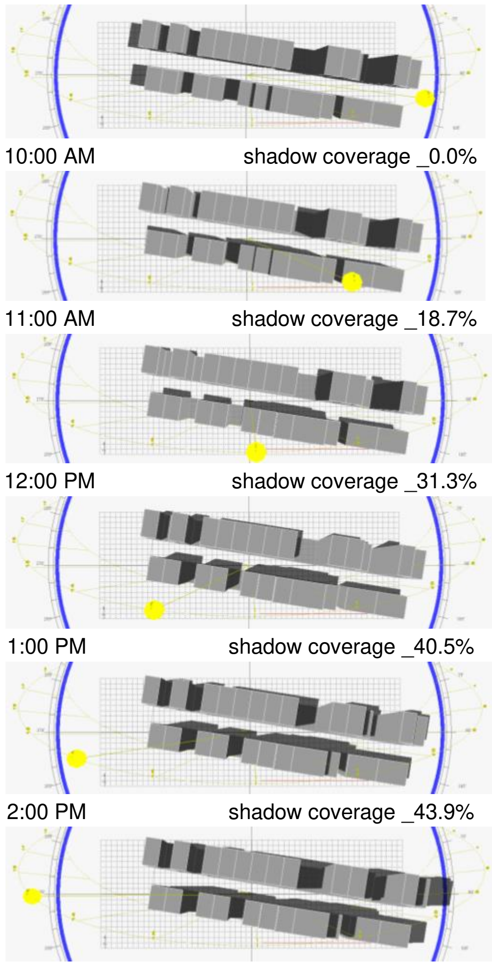

Figure.5. real-time shadow pattern of the study canyon for August,01. (Simulated by author using ecotect5.5.)

Majority of the buildings in the site are tall structures with an average of 14 stories (3.3 m for each storey).
Max 23 and minimum 4 storied buildings are observed. The canyon road width is 18 m and is completely devoid of any tree and vegetation. The existing building fabric together with the road in between forms a deep canyon with an average width and height ratio of 0.4. But the canyon height, in particular, is not equal on both side, hence the canyon can be delineated as an asymmetric one. Both step-up and step-down configuration of canyon exists. The Fig 4 shows the geometric profile of the study canyon. The long axis of the canyon is oriented along east west direction (9 deg deviation from the true horizontal) where the individual plots are facing the north south. It can be assumed that
the location of the vacant plots in the prevalent wind direction may have considerable impact on the wind flow pattern of the study canyon. However the study has limited scope to investigate how much these vacant plots are contributing to the local wind pattern. The study analyzed the local shadow pattern in the canyon during study period (1st august, 2011) using *ecotect 5.5 ®* . It is found that during mid day when the air temp is maximum shadow coverage is highest in the canyon. From 1 pm to 3 pm more than 40% area remains shaded and the maximum shadow coverage is observed at 2.00 pm which is about 44% of canyon area (Fig 5). This is the statistics of that period of the year when the sun is at its highest altitude in annual sun path. Shadow coverage, however, is much higher in rest of the year than this period. Most importantly this particular microclimatic feature has significant impact on the pedestrian movement in study canyon. It is observed that most of the vendors and public gatherings are taken place along the south side of the canyon in the area that remains shaded for most part of the day.

6. IMPACTS OF URBAN CANYON ON TEMPERATURE, HUMIDITY AND WIND SPEED

A study of urban microclimates in Colombo shows as the height to width ratio increases, the maximum daily temperature within the urban canyons decreases [13]. In the study area the comparison of the maximum temperature within the canyon (T_s) and Dhaka's maximum temperature (T_d) as recorded by Meteorological dept. also support the above stated assertion.

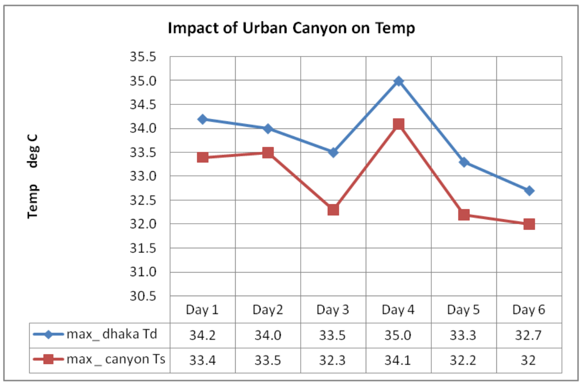

Figure.6. comparison between Canyon temp (Ts) and local temp of Dhaka(Td).

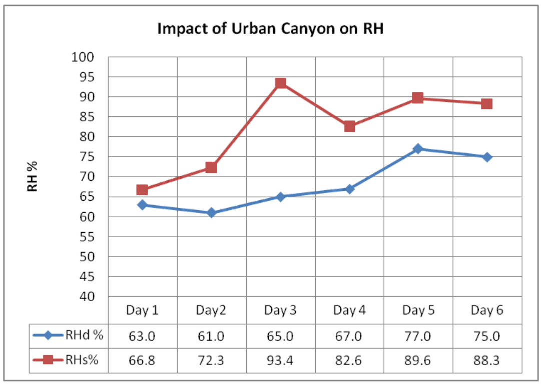

Figure.7. Comparison of Relative Humidity between study canyon (RHs%) and Dhaka (RHd%)

During study period the highest temperature of Dhaka as recorded was 35^{0}C (August 01, 2011) and lowest was 32.7^{0}C (August 03, 2011) where as highest canyon temp was 34^{0}C and lowest was 32^{0}C for the same day (considering max temp only). The analysis shows that T_s is usually 1^{0}C lower than T_d (Fig. 6). This is due to mutual shading of the tall structures that form the canyon.

The humidity measurements in the site show an occurrence of high humidity within the canyon (Fig. 7). Due to compact and continuous urban block humid air cannot escape; a more unlikely phenomenon in case of disperse settlements. Also a mass of high rise blocks can force the air into an upward direction and as the air rises upwards its temperature decreases and the amount of moisture increases [7]. The upwards current of air can also generate from the heated ground surface where the ground is mostly covered with absorbent surfaces. Therefore city centres in many urban areas shows a higher frequency of rain [7]. The findings from this study show a higher range of humidity than the surrounding urban areas.

Again the street level wind flow is negatively affected by the greater H/W ratio [13]. In case of very dense urban settlements wind flow can be hampered resulting in reduced ventilation cooling.

Although higher density of urban arrangement can contribute to a lower air temperature through mutual shading, it can significantly lessen the ability of wind driven cooling due to obstructions if not accurately oriented [13, 14]. The buildings in the study area are attached with one another leaving no a gap in between which creates a wind tunnel effect in the site. Also the presence of vacant sites and height variations of the high rise structures makes the wind pattern extremely complex. According to Kofoed and Gaardsted [15] wind flow pattern in the pedestrian level (1.5 m above the ground) in urban areas is very complex which can be affected by very little alteration urban arrangements. Research findings on 10 deep canyons by Santamouris et al [6] show that it is very difficult to achieve natural ventilation in urban canyons as wind velocity hardly exceeds 1 m/s. A further study on air flow pattern in symmetric and asymmetric canyon by Santiago and Martin [16] also supports this assertion. The study shows that in W/H=0.5 configuration, two counter rotating vortices appear and the lower vortex is much weaker than other (fig. 8). The analyses of the wind data inside the study area show a range of values more than 1. Avg. wind speed in the canyon is 1.3 m/s with min 0.4m/s and max 2.0 m/s as recorded (fig.9). Existence of number of vacant plots on both windward

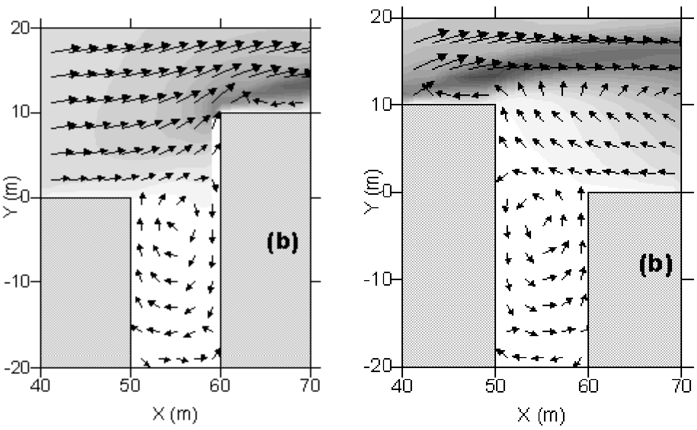

Figure.8. Wind flow pattern for step- up and step- down canyon configuration of W/H=0.5. (Source: Santiago et al, 2005)

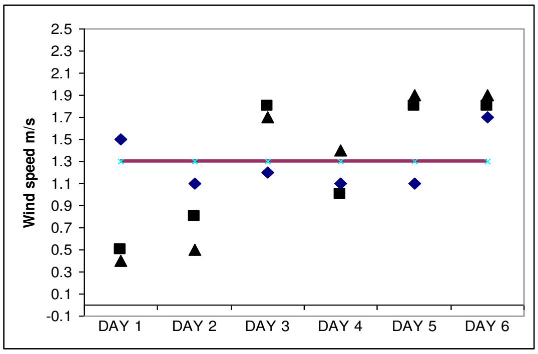

Figure.9. Wind speed in the study canyon as recorded.

and leeward sides has resulted into a higher wind speed in the canyon.

7. IMPACTS OF URBAN CANYON ON OUTDOOR THERMAL COMFORT

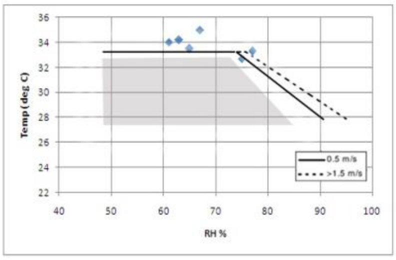

Figure.10a. State of outdoor environment

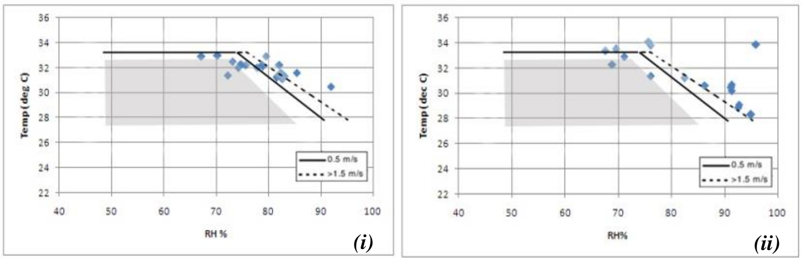

Figure.10b. State of outdoor environment (i) 12:00-1:30 pm, (ii) 1:30-3:00 pm

Respondent type	State of Outdoor Environment				Subjective Response		
	Day	Air temp (deg C)	RH%	Wind speed (m/s)	Comfort sensation: general	Comfort sensation: Specific	Clo
Outdoor type	Day 5	30.4	89.6	1.6	Comfortable (100%)	44% Neutral , 56% slightly warm	.4 -.5
	Day 6	30.8	88.3	1.8	Predominantly Comfortable (90.9%)	50% Neutral, 40.9% slightly warm 9.1% warm	.4 -.5
Indoor type	Day 2	32.6	72.3	1.4	Predominantly Comfortable (80%)	14% Neutral, 66% slightly warm 20% warm	.5
	Day 3	28.8	93.4	1.6	Predominantly Comfortable (80%)	20% Neutral, 60% slightly warm 20% warm	.5

Source: calculated by author *time: 12:00 – 1:30 pm, observation period _ July 27 – Aug 03, 2011*

Figure 11. Comfort responses from outdoor and indoor-type respondents

All the recorded temp and subsequent relative humidity data are plotted in the comfort chart developed by Ahmed [5] to understand whether the prevailing outdoor environment inside and outside the canyon were comfortable or not. Analysis shows that for most of the days during study period outdoor environment of Dhaka in midday was not comfortable. A moderate deviation is observed in case of data recorded inside the canyon during 12 to 1:30 pm where most data fall within the fringe area of comfort zone. A close look to the data also reveals that in spite of high humidity the presence of low temp and moderate wind flow often confine canyon environment as comfortable one. To evaluate this finding with the field response all the environmental data are plotted against the corresponding subjective response of comfort sensation. It is found that except day 6, outdoor canyon environment at 1:30 to 3:00 pm was 'uncomfortable' where as the it was perceived as 'comfortable' by the most of the respondents at 12 to 1:30 pm during study period with an exception in day 4 (fig. 10).

Although the sensation of comfort varies for indoor and outdoor type occupants but in both cases it is largely influenced by the air temperature. Based on findings, statistics of most comfortable days during study period as perceived by the respondents is given in Fig. 11. Research findings from Nikolopoulou and Steemers [1] state that "people who have a high degree of control over a source of discomfort, tolerate wide variations, are less annoyed by it, and the negative emotional responses are greatly reduced." Fig. 11 which presents comfort responses from outdoor and indoor-type respondents however reveals an opposite scenario.

Throughout the study period larger amount of outdoor type people were less satisfied with the thermal environment in comparison to the indoor type. This is because most of the outdoor-type people were engaged in heavy physical works like building construction or rickshaw pulling. On the other hand, majority of the indoor-type people were exposed to discomfort for a shorter period of time. Outdoor-type interviewees' thermal sensation votes (ASVs) were mostly recorded in the +1 warm category.

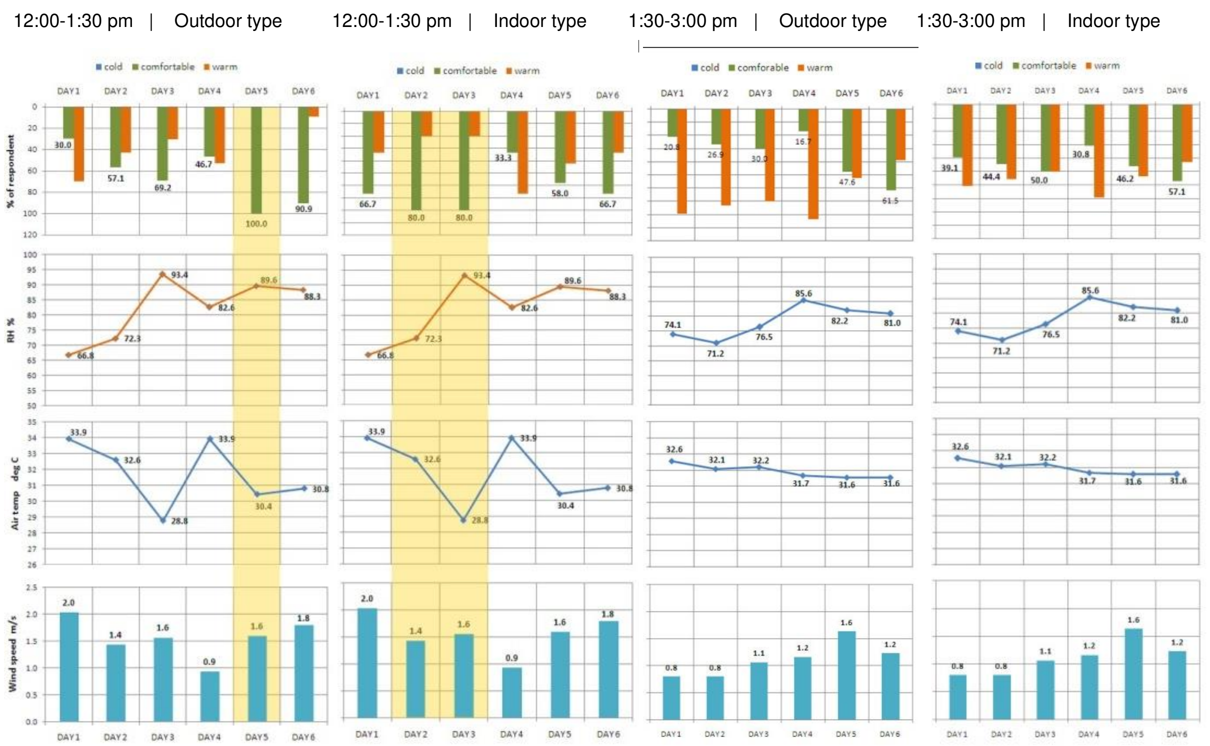

Figure.10. Subjective response of comfort sensation against the prevailing Air temp , RH% and Wind speed in the study canyon

Apart from the above, there are few other factors that influence the outdoor comfort specially in a commercial urban area. Almost every building in the study canyon is mechanically ventilated and depended on air conditioners. Due to frequent load shedding, a very common phenomenon for Bangladesh, they have to depend on generators during the load shedding hours. Throughout the study period maximum noise level was recorded as 106.5 db and minimum 69.5 db with an average of 78 db. The heat, noise and fumes generated by both air conditioners and generators often results in an uncomfortable physical as well as psychological environment.

8. FINDINGS

A quantitative approach to the climatic parameters has confirmed that physical configuration of the urban canyon greatly affects its thermal environment. Building geometry and urban morphology as a whole influence the solar radiation, air temperature and wind in the open spaces. The following conclusions can be drawn from the present study:

- The maximum air temperature in a deep canyon is found to be lower than that of Dhaka's maximum ranges as recorded in the meteorological stations.

- Another finding from the study is wind velocity within the canyon is typically low except around the vacant plots. Therefore it can be claimed that Void on windward side provides comfortable outdoor environment even in most hot-humid period of the year in tropical cities. But it is often difficult to inject void in a commercial development due to its high land value. An alternative use of this void as an urban open space may enhance the quality of outdoor environment and thus physical and psychological comfort of the user. However more comprehensive study is required to understand the optimum requirements of the void for deep canyon.

9. CONCLUSION

Returning to the hypothesis posed at the beginning of this study, it is now possible to state that a careful design of urban spaces can lead to a thermally comfortable microclimate. The use of outdoor spaces can be enhanced by appropriate microclimatic planning by offering shelter from harmful features and exposure to positive features of the climate. Through this study it will be possible to explore outdoor microclimatic characteristics and the comfort implications for the people using them, thereby revealing new potentials for the sustainable development of urban spaces. The findings in this study add substantially to the understanding of thermal comfort in urban spaces in the context of Dhaka. It confirms previous findings and explains the significance of comfort in outdoor urban spaces.

10. LIMITATIONS OF THE STUDY

A number of caveats need to be noted regarding the present study. First, the study was carried out with the help of regular hand held instruments whose accuracy is still a matter of question. In the absence of efficient data loggers greater accuracy could not be achieved. The current study was also unable to analyse Mean Radiant Temperature which is an important factor in urban microclimate due to the lack of Pyranometer. A greater technical knowledge and computer simulation skill is required to compare the microclimates in different urban canyons and to develop a better arrangement of urban blocks to achieve a comfortable outdoor environment.

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